Chapter 9

Forecasting the November 2010 eruption of Merapi, Indonesia

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9.1 Background

Merapi volcano, Indonesia (7.542°S 110.442°E) is one of the most active and hazardous volcanoes in the world. A large population settled on and around the flanks of the volcano is at risk. Over the past century eruptions were characterised by frequent small to moderate intensity eruptions, with pyroclastic flows produced by lava dome collapse. The most recent eruption in 2010 was of unusually high intensity. In late October and early November 2010, the volcano produced its largest and most explosive eruptions since 1872, displacing about 400,000 people, and claiming nearly 400 lives.

9.2 Monitoring

A seismic network has been in place on Merapi since 1982 to identify different kinds of earthquakes that are informative about the potential for eruption. Deformation is measured using Electronic Distance Measurements (EDM) of line lengths from the flanks to reflectors near the summit, and (since 2010) also with Global Positioning Satellite (GPS) receivers. Sulfur dioxide gas (SO_2) is routinely measured at Merapi using ultraviolet absorption spectrometers. SO_2 is commonly chosen as the gas to monitor as the atmosphere normally contains only trace amounts so it is relatively easy to detect. During volcanic quiescence the SO_2 is typically emitted at less than 100 tons per day, while the emissions can double or treble during small eruptions.

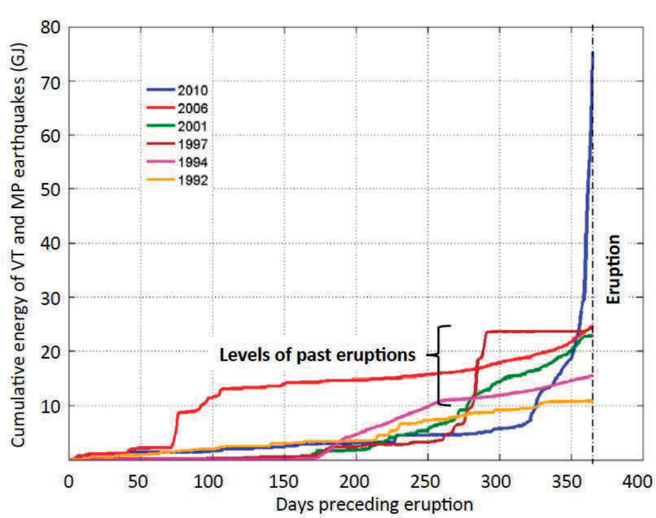

Figure 9.1 Cumulative seismic energy release of volcano-tectonic (VT) and multiphase (MP) earthquakes for eruptions of Merapi in 1997, 2001, 2006 and 26 October 2010. Modified from Budi-Santoso et al. (2013).

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9.3 Forecasting the 2010 eruption

Despite the challenges involved in forecasting the 2010 “hundred year eruption", the magnitude of precursory signals (seismicity, ground deformation, gas emissions) was proportional to the large size and intensity of the eruption. Increasing numbers of earthquakes occurred at rates of tens to hundreds of events per day in the weeks before the October 2010 eruption. While increasing seismicity is not a definitive sign of impending eruption it provides an alert of increasing potential. As is common in many volcanoes the earthquakes were located at depths between a few kilometres and the surface. In late September, high levels of CO_2 in summit fumaroles provided early warning of magmatic replenishment. In late October 2010 a series of small phreatomagmatic eruptions took place, with associated SO_2 emissions of tens of thousands of tons per day and peaks in earthquake energy. The observations of exceptionally high gas emissions and high rates of summit deformation as determined with EDM data raised concerns further. In addition and for the first time, near-real-time satellite radar imagery played a major role along with the seismic, geodetic, and gas observations in monitoring and forecasting eruptive activity during a major volcanic crisis. The satellite data documented exceptionally rapid extrusion of a voluminous summit lava dome following the initial phreatomagmatic eruptions and before the climactic eruption on 5 November. Rates of extrusion during 1-4 November were an order of magnitude greater than seen at Merapi during past eruptions, and the resulting summit lava dome quickly reached a volume of ~5 million m^3, and was poised ready to collapse at the break in slope at the edge of the summit by 4 November.

The monitoring data played a key role in anticipating the major eruption of 5 November 2010. Marked escalation in summit deformation, seismic energy, SO_2 and CO_2 emissions, increased temperature of crater fumaroles, and the high extrusion rate of lava observed from satellites led to a major expansion of the evacuated zone [see Chapter 10]. The Indonesian Center of Volcanology and Geological Hazard Mitigation (CVGHM) was able to issue timely warnings of the magnitude of the eruption phases, and evacuations organised by the Indonesian National Board for Disaster Management (BNPB), provincial and local emergency managers saved an estimated 10,000 to 20,000 lives [Chapter 10].

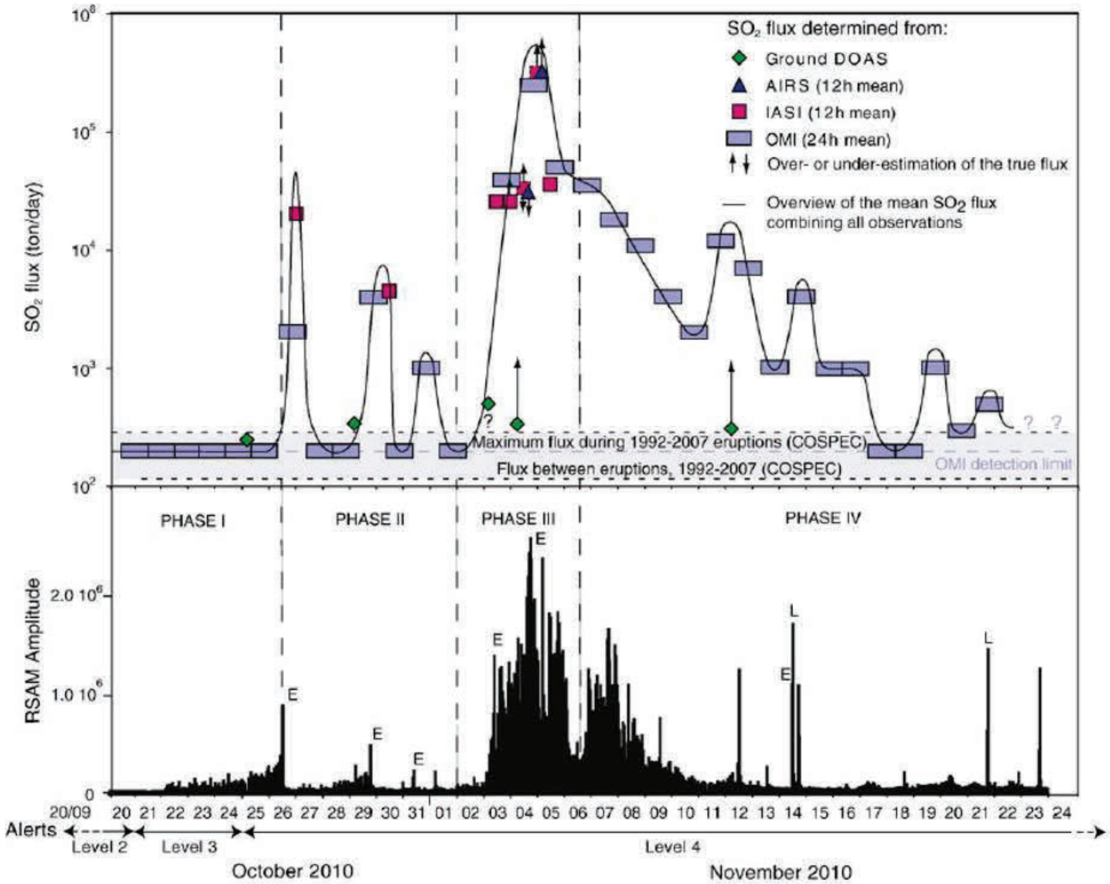

Figure 9.1 Variations in seismic energy (the RSAM amplitude) and SO_2 emissions in October and November 2010. Phases are phreatomagmatic explosive (I), magmatic (II), climactic (III) and waning (IV), E marks eruptions and L marks volcanic mudflows (lahars). RSAM is Real-time Seismic Amplitude Measurement, DOAS is Differential Optical Absorption Spectroscopy, satellite SO_2 measurements are by AIRS (Atmospheric Infrared Sounder), IASI (Infrared Atmospheric Sounding Interferometer) and OMI (Ozone Monitoring Instrument). From Surono et al. (2012)

References

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